# I. Introduction

Today, after decades of dependence on imported petroleum to fuel the United States' transportation sector, there is a new vision for our nation's future — a form of domestically-derived, clean energy to power not only our vehicles but our industries, buildings, and homes. This form of energy for the future is hydrogen. The President's Hydrogen Fuel Initiative complements the FreedomCAR initiative to reverse America's growing dependence on foreign oil. Together the FreedomCAR Partnership and Hydrogen Fuel Initiative support the development of technology needed for commercially viable hydrogen-powered fuel cells. President Bush committed $1.7 billion for the first five years of a long-term research and development effort for hydrogen infrastructure, fuel cells, and hybrid vehicle technologies.

Hydrogen research at the U. S. Department of Energy (DOE) is being led by the Office of Energy Efficiency and Renewable Energy (EERE). Other DOE Offices carrying out portions of the Initiative are Fossil Energy, Nuclear Energy, and Science. Within EERE, hydrogen and fuel cell technologies are being managed by the Office of Hydrogen, Fuel Cells and Infrastructure Technologies. Hybrid and other advanced vehicle technologies are being developed within the Office of FreedomCAR and Vehicle Technologies.

**National Vision**

Hydrogen is America's clean energy choice.

Hydrogen is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country.

The Hydrogen, Fuel Cells and Infrastructure Technologies Program funds research, development, and validation activities linked to public-private partnerships. The government's current role is to concentrate its funding on high-risk, applied research in the early phases of development. As activities progress through the stages of developing technology to validating technical targets, the government's cost share will diminish. The government's role as co-funder will bring technologies to the point where the private sector can make informed decisions on whether or not, and how best to commercialize these technologies, and will define any future policies to promote them.

## Program Mission

The mission of the Hydrogen, Fuel Cells & Infrastructure Technologies Program is to research, develop, and validate fuel cells and hydrogen production, delivery, and storage technologies for transportation and stationary applications.

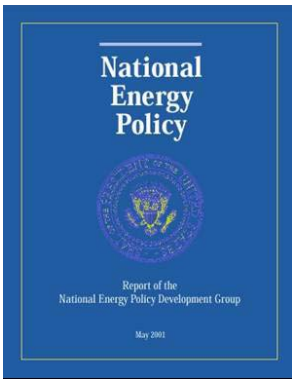
The Hydrogen, Fuel Cells and Infrastructure Technologies Program responds to recommendations in the President's National Energy Policy, the DOE Strategic Plan, and the National Hydrogen Energy Vision and Roadmap. The Program works in partnership with industry, academia, and national laboratories, and in close coordination with the FreedomCAR and Vehicle Technologies Program and other DOE programs, to achieve the four EERE strategic goals:

- Dramatically reduce dependence on foreign oil
- Promote the use of diverse, domestic, and sustainable energy resources
- Reduce carbon emissions from energy production and consumption
- Increase the reliability and efficiency of electricity generation

This report presents a brief overview of DOE's approach to the transition to a hydrogen economy, a description of the fuel cell and hydrogen research conducted by the Hydrogen, Fuel Cells and Infrastructure Technologies Program in fiscal year 2003 (FY 2003), projects to be implemented in FY 2004, and the research priorities for FY 2004.

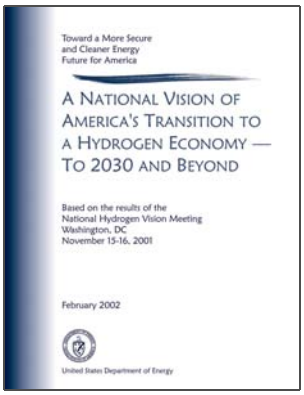
# The Journey Toward a Hydrogen Economy

The transition to a hydrogen economy can be compared to a journey to unknown places, with many challenges to overcome, similar to those which faced our first manned space explorations. DOE has taken the first step toward a hydrogen economy by developing vision, roadmap and long-term planning documents. The planning documents are based on the Administration's National Energy Policy and include input from visionary business leaders and policy makers. The following is a brief description of these documents and other plans that support the President's Hydrogen Fuel Initiative.




The National Energy Policy, released in May 2001, outlines a long-term strategy for developing and using leading-edge technology within the context of an integrated national energy, environmental, and economic policy. It specifically highlighted the potential of hydrogen with the following recommendations:

- Focus research and development efforts on integrating current programs regarding hydrogen, fuel cells, and distributed energy.
- Develop an education campaign that communicates the benefits of alternative forms of energy, including hydrogen.

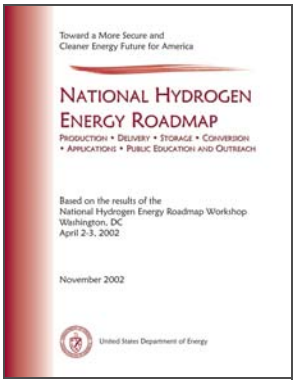



In November 2001, in response to recommendations within the National Energy Policy, DOE organized a meeting of 50 visionary business leaders and policy makers to formulate a National Hydrogen Vision. ***A National Vision of America's Transition to a Hydrogen Economy-to 2030 and Beyond*** was published in February 2002 following the Hydrogen Vision Meeting. This document summarizes the potential role for hydrogen systems in America's energy future, outlining the common vision of the hydrogen economy.

In January 2002, Secretary of Energy Spencer Abraham announced the FreedomCAR Partnership, a cooperative research effort between DOE and USCAR, which is composed of DaimlerChrysler Corporation, Ford Motor Company and General Motors Corporation. FreedomCAR is based upon the following principles:

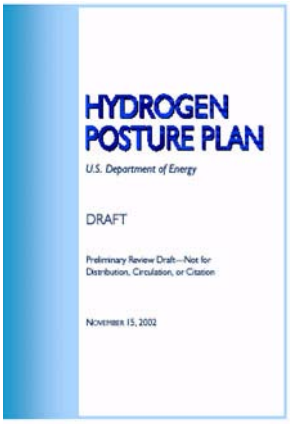
1. Freedom from petroleum dependence
2. Freedom from air pollutant and carbon dioxide emissions
3. Freedom for Americans to drive where they want, when they want, in the vehicle of their choice
4. Freedom to obtain fuel more affordably and conveniently

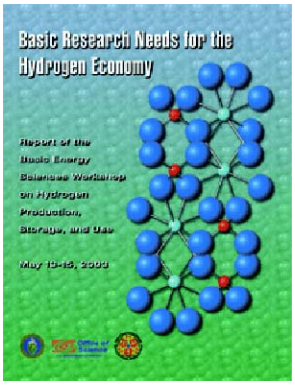
The companies of the FreedomCAR Partnership will be at the forefront of development of vehicle technologies for implementation of the hydrogen economy.



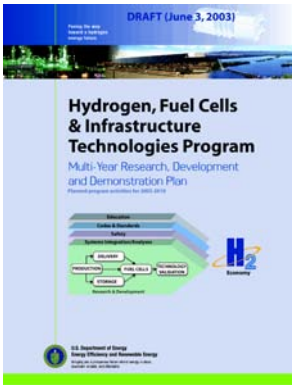

In April 2002, DOE followed up with a larger group of over 200 technical experts from industry, academia, and the national laboratories to develop a **National Hydrogen Energy Roadmap**. This roadmap, unveiled by Secretary Abraham in November 2002, describes the principal challenges to be overcome and suggests ways we can achieve our National Vision. To realize this vision, the Nation must develop and demonstrate advanced hydrogen fuel cell and infrastructure technologies. The Roadmap stresses the need for parallel development of model building codes and equipment standards to enable technology integration into commercial energy systems, and outreach programs to effectively educate local government officials and the public, who will determine the long-term acceptance of these technologies.

In February 2003, DOE completed a draft copy of the ***Hydrogen Posture Plan***. The Hydrogen Posture Plan describes how DOE will integrate its ongoing and future hydrogen R&D activities into a focused Hydrogen Program. It defines four phases of transition to a hydrogen economy (see the following subsection titled *The Road to a Transition* for detailed descriptions of each). The Hydrogen Program will integrate technology for hydrogen production (from fossil, nuclear, and renewable resources), infrastructure development (including delivery and storage), and fuel cells. Successful implementation of the Hydrogen Posture Plan and its activities is also critical to achieving the goals of the FreedomCAR Partnership. A coordinated DOE Hydrogen Program will improve the effectiveness and accountability of DOE's research, development, and demonstration (RD&D) activities and strengthen its contribution to achieving the technical milestones on the road to a hydrogen economy.




The Office of Science hosted a workshop on Hydrogen Production, Storage, and Use, on May 13–15, 2003, to identify fundamental research needs and opportunities to address the enormous gap between our present capabilities for hydrogen production, storage, and use, and those required for a competitive hydrogen economy. More than 120 scientists and engineers from academia, industry, and the national laboratories attended. Participants also included research leaders from abroad and experts from the Offices of Energy Efficiency and Renewable Energy, Fossil Energy, and Nuclear Energy within the U.S. Department of Energy. The detailed findings and research directions (http://www.sc.doe.gov/bes/hydrogen.pdf) address the research challenges for the hydrogen economy. The workshop report concludes that simple improvements of today's technologies will not meet the requirements. Instead, the significant technical barriers need to be overcome with high risk/high payoff basic research that is highly interdisciplinary, requiring chemistry, materials science, physics, biology, engineering, nanoscience, and computational science. It also calls for the seamless integration of basic and applied research to realize the successful transition to a hydrogen economy.




The Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan was prepared for public review and released on June 3, 2003. The Plan describes the planned research, development, and validation activities for hydrogen and fuel cell technologies through nine key program components through 2010.

| | |
|---|---|
| Production | Production of hydrogen from domestic resources minimizing environmental impacts |
| Delivery | Distribution of hydrogen from centralized or from distributed sites of production |
| Storage | Storage of hydrogen (or its precursors) on vehicles or within the distribution system |
| Fuel Cells | Provide primary propulsion for fuel cell vehicles, serve as auxiliary power units for vehicles, and provide electrical and thermal power in stationary and portable applications. |
| Technology Validation | Validation of systems in real-world environments |
| Safety | Safety assurance in DOE-sponsored R&D activities and in the hydrogen systems developed |
| Codes and Standards | Development of model codes and standards for domestic and international production, distribution, storage and utilization of hydrogen |

| | |
|---|---|
| Education | Education of key target audiences—including teachers and students, state and local governments, safety and code officials, large-scale end users, and the public—about the hydrogen economy and how it can affect them |
| Systems Integration | Understanding the complex interactions between components, system costs, energy efficiency, environmental impacts, societal impacts and system trade-offs |

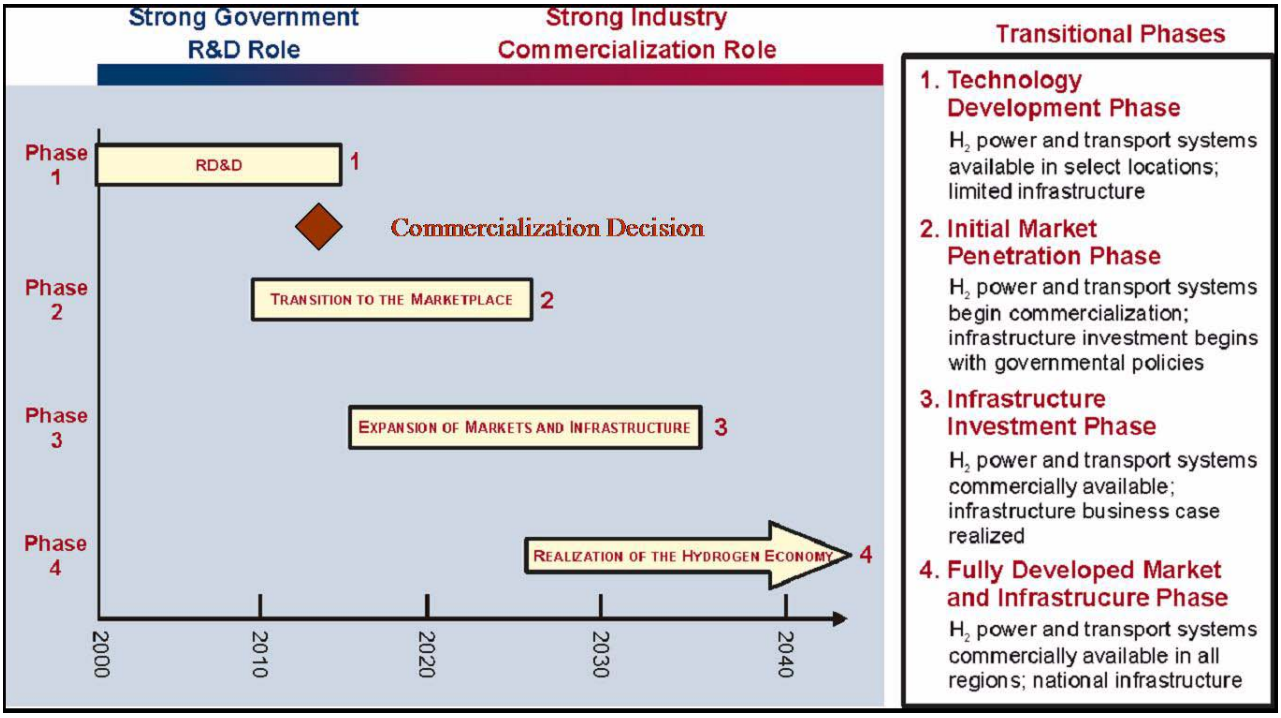
The detailed technical targets and milestones for each element are identified in the Plan.

## The Road to Transition

Throughout the planning process, DOE has envisioned four phases in the transition to a hydrogen economy, each of which requires and builds on the success of its predecessor. The transition to a hydrogen economy will take several decades, and this transition will require strong public and private partnerships, commitment, and resolve.

In Phase 1, government and private organizations will research, develop, and demonstrate "critical path" technologies and work to establish comprehensive safety guidelines, codes and standards prior to investing heavily in infrastructure. This phase is now underway, and it will enable industry to make decisions on commercialization by 2015. Following a positive commercialization decision, research will continue on advanced technologies for hydrogen production. Throughout the RD&D phase, exploratory research in materials sciences and engineering, chemistry, geosciences, and molecular biosciences will be carried out in close collaboration with the DOE Office of Science.

Phase 2 is the Initial Market Penetration Phase. This could begin as early as 2010 using existing natural gas and electric grid infrastructure for applications such as portable power and some stationary and transportation applications, and continue as hydrogen-related technologies meet or exceed customer requirements.

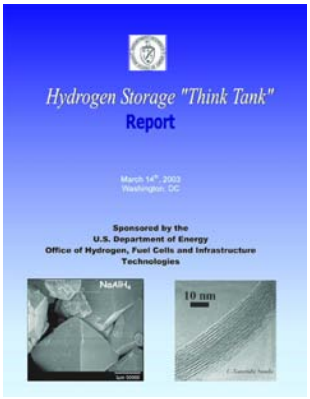


As markets are established, this leads to Phase 3, or the Infrastructure Investment Phase, in which there is expansion of markets and infrastructure. The start of Phase 3 is dependent on a positive commercialization decision for fuel cell vehicles in 2015. A positive decision will attract investment in infrastructure for manufacturing fuel cells and for producing and distributing hydrogen. Government policies still may be required to nurture this infrastructure expansion phase.

Phase 4, which could begin around 2025, is the Fully Developed Market and Infrastructure Phase. In this phase, consumer requirements will be met or exceeded, national benefits in terms of energy security and improved environmental quality will be achieved, and industry will receive adequate return on investment and compete globally. Phase 4 provides the transition to a full hydrogen economy by 2040.

## Progress Along the Road to Transition

As discussed, detailed planning for the President's Hydrogen Fuel Initiative was completed during FY 2003. The following is a brief list of accomplishments achieved:




- The Office of Energy Efficiency and Renewable Energy hosted a hydrogen storage "Think Tank" meeting in Washington, D.C., on March 14, 2003, to identify new and potentially promising hydrogen storage technologies. Based on the Think Tank meeting, which included Nobel Prize Laureates, the DOE issued a "Grand Challenge" to the scientific community to solicit applications for research and development of hydrogen storage materials and technologies. The awards made from this solicitation will establish Centers of Excellence.
- The Office of Fossil Energy launched FutureGen, a $1 billion, 10-year verification project that will build the world's first coal-based, near zero-emission electricity and hydrogen plant integrated with carbon sequestration.
- The DOE sponsored a Hydrogen Delivery Workshop in Washington, DC, May 7-8, 2003. Attendees included researchers, government officials, and industry members. This special workshop was held to outline the future technology and research needs for developing cost-effective, reliable, and safe hydrogen delivery systems.
- On June 2-3, 2003, DOE held a Hydrogen and Fuel Cells Coordination Meeting to facilitate communication and coordination among the DOE programs with key roles in achieving the goals of the President's FreedomCAR and Hydrogen Fuel Initiative. The meeting was attended by invited participants from programs in DOE's Offices of Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, Science and Technology, Science, and the Office of Management, Budget and Evaluation.
- The world's first hydrogen and electricity co-production facility opened in Las Vegas, Nevada, in November 2002. The facility (built by Air Products and Chemicals, Inc., in partnership with Plug Power Inc., the DOE, and the City of Las Vegas) will serve as a "learning" demonstration of hydrogen as a safe and clean energy alternative for vehicle refueling. The facility includes small-scale, on-site hydrogen production technologies, a hydrogen/compressed natural gas blend refueling facility, and a 50-kW PEM fuel cell system that supplies electricity to the grid.
- The Office of Energy Efficiency and Renewable Energy released a hydrogen production and delivery technologies solicitation which includes the following topics: biomass gasification and pyrolysis; photolytic processes; distributed natural gas reforming technologies; separation and purification technologies; advanced electrolysis

World's First Hydrogen and Electricity Co-Production Facility

systems; high temperature thermochemical water splitting; hydrogen production infrastructure analysis; and advanced hydrogen delivery technologies. Pre-proposals have been received with proposals due in FY 2004.

- Hosted workshop for education and industry experts to launch a new education program element, December 4-5, 2002.
- The Office of Energy Efficiency and Renewable Energy issued a solicitation for the testing, demonstration, and validation of hydrogen fuel cell vehicles and infrastructure, and the required vehicle and infrastructure interfaces for complete system solutions. The awards will be cost-shared, and each will include a comprehensive safety plan; a program that enhances the development of codes and standards; and a comprehensive, integrated education and training campaign. Awards will be made in FY 2004, and each will be 5 years in length.

**Stationary/Transportation Awards Announced**
**July 14, 2003**

| Company | Project Technology |
|---|---|
| 3M Company | MEA and Stack Durability |
| IdaTech LLC | Stationary Fuel Cell Power System |
| UTC Fuel Cells LLC | Stationary Fuel Cell Power System & Demo |
| Plug Power, Inc. | Back-up/Peak Shaving Fuel Cells |
| Atofina Chemicals, Inc. | Low Cost, Durable Membranes |
| DuPont | MEA Durability |
| Plug Power, Inc. | High Temperature Membranes |
| Texaco Energy Systems | Fuel Cell Fuel Processor |
| Honeywell International Inc. | Thermal and Water Management |
| Engelhard Corporation | Platinum Recycling |
| Ion Power, Inc. | Platinum Recycling |
| 3M Company | Non-Precious Metal Catalysts |
| Ballard Power Systems Corp. | Non-Precious Metal Catalysts |
| University of South Carolina | Non-Precious Metal Catalysts |
| Battelle Memorial Institute | Economic Analysis |

- The FreedomCAR Partnership was expanded to include energy companies to focus on hydrogen infrastructure challenges.
- On March 21-22, 2003, DOE sponsored the Non-Platinum Electrocatalyst Workshop to review and identify potential new candidate electrocatalysts that are non-platinum (and non-precious metal). Fifty-five representatives from universities, government agencies, national laboratories, and private industry attended the two-day workshop, held in New Orleans, Louisiana.
- Safety guidelines for DOE Hydrogen Program projects were drafted.
- The Office of Energy Efficiency and Renewable Energy Launched a hydrogen education "campaign" as recommended in the President's National Energy Policy.
  A solicitation was released with proposals due in the beginning of FY 2004.
- Initiated a review by The National Academies of DOE's hydrogen research, development, and demonstration (RD&D) program. An interim letter report was received April 3, 2003, which provides some early feedback and recommendations. A final report is anticipated in FY 2004.
- Energy Efficiency and Renewable Energy conducted a merit review and peer evaluation of all the projects in the Hydrogen, Fuel Cells and Infrastructure Technologies Program. The results of this meeting will be used to guide research activities during FY 2004.
- DOE Awarded a total of $96 million in 24 new awards in support of the President's FreedomCAR and Hydrogen Fuel Initiative. These new projects include research in advanced fuel cell technology for vehicles, buildings and other applications. In particular, the projects on hydrogen storage technologies support DOE's priority to develop methods to safely store hydrogen to enable at least a 300 mile vehicle range—a critical requirement for successful vehicle commercialization. The recipients of these awards have pledged an additional $40 million in cost sharing, bringing the total value of these projects to $136 million.

## Future Plans for Progress Along the Road to Transition

The following are the FY 2004 priorities for the FreedomCAR and Hydrogen Fuel Initiative:

- Establish the International Partnership for a Hydrogen Economy (IPHE). The objective of the IPHE is to efficiently organize, evaluate and coordinate multinational research, development and deployment programs that advance the transition to a global hydrogen economy.
- Establish a fully integrated DOE Hydrogen Program to efficiently manage all DOE hydrogen and fuel cell research and include an innovative systems integration capability to cost effectively execute all aspects of the President's Hydrogen Fuel Initiative.
- Finalize and publish the 5-year hydrogen RD&D plans of the Offices of Energy Efficiency and Renewable Energy, Fossil Energy, and Nuclear Energy based on the peer review by The National Academies.
- Conduct an integrated DOE Hydrogen Program merit review and peer evaluation meeting including the Offices of Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, and Science.
- Establish three to four Hydrogen Storage Centers of Excellence led by DOE national laboratories including universities, industry, and/or other federal/national laboratories as partners to address the very pressing needs to improve hydrogen storage so that fuel cell vehicles with 300 mile range can become a practical reality.
- Issue solicitation for hydrogen production from coal and award projects.
- Initiate a national Hydrogen Vehicle and Infrastructure Validation Project with three to six consortia (auto/ fuel/ supplier teams) to test vehicles and infrastructure. Data from these "learning" demonstrations will provide feedback to the research program.
- Establish an expert panel to analyze the merits of whether to continue development of on-board fuel processors to reform gasoline and alternative fuels such as methanol, ethanol, and natural gas to produce hydrogen on-board the vehicle.
- Initiate high efficiency polymer electrolyte membrane stationary fuel cell power system projects that will advance and demonstrate the use of fuel cells as an alternative power source to grid-based electricity for buildings.
- Select up to 32 projects to receive up to $80 million of federal funding for development of hydrogen production and delivery technologies.
- Establish and implement a data management plan for the DOE Hydrogen Program.
- Conduct and report on baseline assessment of key target audiences' understanding of hydrogen economy.
- Launch first phase of long-term education strategy by creating hydrogen information clearinghouse to serve multiple audiences and initiating specific education activities focused on teachers and students and state and local governments.
- Conduct a scoping study for a Programmatic Environmental Impact Statement.
- Initiate worldwide commitment for global hydrogen codes and standards as part of on-going IPHE activities.
- Launch the Office of Nuclear Energy Hydrogen Initiative which will demonstrate the economic commercial-scale production of hydrogen using nuclear energy by 2015.

**Hydrogen Storage/Sensors Awards**
**July 14, 2003**

| Company | Project Technology |
|---|---|
| Air Products & Chemicals, Inc. | Hydrogen Storage |
| Cleveland State University | Hydrogen Storage |
| Intelligent Optical Systems, Inc. | Sensors |
| Iowa State University | Hydrogen Production |
| Millennium Cell, Inc. | Hydrogen Storage |
| Nanomix, Inc. | Hydrogen Storage |
| QUANTUM Technologies, Inc. | Hydrogen Storage |
| Safe Hydrogen, LLC | Hydrogen Storage |
| United Technologies Research Center | Hydrogen Storage |
| University of California, Irvine | Sensors |
| UOP, LLC | Hydrogen Storage |

- Continue efforts to establish closer relationships with the states through the DOE Regional Offices to execute hydrogen and fuel cell RD&D, especially in the areas of education and codes/standards.

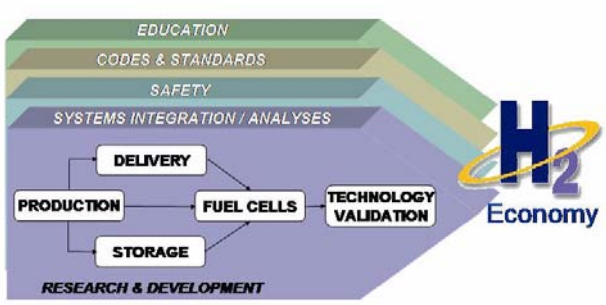
### The National Academies Review

The DOE asked The National Academies in December 2002 to evaluate the cost and status of technologies for production, transportation, storage, and end-use of hydrogen and to review DOE's hydrogen research, development, and deployment (RD&D) strategy. On April 4, 2003, The National Academies submitted their interim report offering four recommendations in the following areas:

- Safety: The Committee recommended that DOE make significant efforts to address safety issues.
- Systems Integration and Analyses: The National Academies recommended that R&D successes & failures be analyzed and modeled both as individual technologies and as components of a greater system.
- Exploratory Research: The Committee encouraged DOE to continue funding fundamental, exploratory research for promising, high-risk new technologies.
- Organization: The Committee supports the DOE in its efforts to integrate various hydrogen-related RD&D programs, the Office of Science, and the private sector.

A final report will be submitted during FY 2004. FreedomCAR and the Hydrogen Fuel Initiative are focused on bringing about significant changes to how the country develops and uses its energy resources. The DOE is highly interested in the findings and recommendations of The National Academies so that we can guide the program in a way that achieves the best results for the country. Find more information at www.nas.edu under BEES-J-02-04-A.

## Technical Challenges and Mileposts Along the Road to Transition




The EERE Hydrogen, Fuel Cells and Infrastructure Technologies Program has set goals and targets for each of its technical areas. The "core" activities are hydrogen production, delivery, and storage; fuel cell development; and validation technology. Cross-cutting activities of systems integration/analysis, safety, codes and standards, and education are performed in parallel with the technology research and development activities. Following are brief descriptions of the status of these Program activities, the goal for each, pertinent technical targets, current status, and anticipated FY 2004 accomplishments.

### Hydrogen Production

Goal: Research and develop low-cost, highly efficient hydrogen production technologies from diverse, domestic sources, including fossil, nuclear, and renewable sources.

Objectives

- By 2010, reduce the cost of distributed production of hydrogen from natural gas and/or liquid fuels to $1.50/kg (delivered, untaxed) at the pump (without carbon sequestration).

- By 2010, develop and demonstrate technology to supply purified hydrogen (purity sufficient for PEM fuel cells) from biomass at $2.60/kg at the plant gate (projected to a commercial scale 75,000 kg/day).[1] The objective is to be competitive with gasoline by 2015.
- Develop advanced renewable photolytic hydrogen generation technologies. By 2015, demonstrate an engineering-scale biological system that produces hydrogen at a plant-gate cost of $10/kg projected to commercial scale. By 2015, demonstrate direct photoelectrochemical water splitting with a plant-gate hydrogen production cost of $5/kg projected to commercial scale. The long-term objective for these production routes is to be competitive with gasoline.
- By 2010, verify renewable integrated hydrogen production with water electrolysis at a hydrogen cost of $2.50/kg (electrolyzer capital cost of $300/kW$_e$ for 250 kg/day at 5,000 psi with 73% system efficiency). By 2010, verify large-scale central electrolysis at $2.00/kg hydrogen at the plant gate.
- By 2015, research and develop high- and ultra-high-temperature thermochemical/electrical processes to convert hydrogen from high temperature heat sources (nuclear or solar) with a projected cost competitive with gasoline.[2]
- Evaluate other new technologies that have the potential for cost-effective sustainable production of hydrogen and fund appropriate research and development (R&D) in promising areas.

FY 2003 Status

- Cost of distributed production of hydrogen from natural gas: $5.00/kg
- Cost of centralized production of hydrogen from biomass: $4.00/kg (at the plant gate)

Anticipated FY 2004 Accomplishments

- Complete research to enable distributed natural gas reforming technologies delivering 5,000 psi hydrogen at $3.00/kg hydrogen – progress toward achieving 2010 goal of $1.50/kg.
- Accelerate and expand research to reduce the cost of electrolysis for hydrogen production, including high temperature steam electrolysis, and complete an analysis and research on central, integrated, wind-based electrolysis.
- Initiate a geothermal-based electrolysis feasibility study.
- Accelerate and expand research on the production of hydrogen from renewable resources, including biomass gasification/pyrolysis, photobiological and photoelectrochemical production.
- Initiate research on high temperature thermochemical water splitting for hydrogen production.
- Complete a comprehensive techno-economic analysis of the major production options for hydrogen on a consistent and comparable basis.

## Hydrogen Delivery

Goal: Develop hydrogen fuel delivery technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power.

Objectives

- By 2006, define a cost-effective and energy-efficient hydrogen fuel delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.
- By 2010, develop enabling technologies to reduce the cost of hydrogen fuel delivery from central and semi-central production facilities to the gate of refueling stations and other end users to <$0.70/kg.
- By 2010, develop enabling technologies to reduce the cost of moving and handling hydrogen within refueling stations and stationary power facilities to a vehicle or stationary power unit to <$0.60/kg.

1. Collaboration with the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Biomass Program. Offsets for coproducts not included.
2. Collaboration with DOE's Office of Nuclear Energy.

- By 2015, develop enabling technologies to reduce the cost of hydrogen fuel delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/kg in total.

FY 2003 Status

- Cost of gaseous hydrogen compression: $0.18/kg; efficiency of 90%
- Cost of hydrogen liquefaction: $1.11/kg; efficiency of 65%
- Cost of hydrogen trunk pipelines: $1.4 million/mile
- Cost of hydrogen distribution lines: $600,000/mile
- Hydrogen carrier storage capacity: 3 wt.%; efficiency of 80%

Anticipated FY 2004 Accomplishments

- Define and initiate a comprehensive analysis of hydrogen delivery technology and infrastructure options and trade-offs.
- Initiate research projects on hydrogen delivery to support the 2005 and 2010 delivery targets, including lower cost pipelines, compression and liquefaction technology and novel solid and liquid carrier systems.

## Hydrogen Storage

Goal: Develop and demonstrate viable hydrogen storage technologies for transportation and stationary applications.

Objectives

- By 2005, develop and verify on-board hydrogen storage systems achieving 1.5 kWh/kg (4.5 wt%), 1.2 kWh/L, and $6/kWh.
- By 2010, develop and verify on-board hydrogen storage systems achieving 2 k Wh/kg (6 wt%), 1.5 kWh/L, and $4/kWh.
- By 2015, develop and verify on-board hydrogen storage systems achieving 3k Wh/kg (9 wt%), 2.7 kWh/L, and $2/kWh.
- By 2015, develop and verify low-cost, off-board hydrogen storage systems, as required for hydrogen infrastructure needs to support transportation, stationary and portable power markets.

FY 2003 Status

- For 10,000 psi tanks: Achieved factor of 10 improvement in cycle life and demonstrated 3-minute fill time.
- For solid state materials: Achieved factor of 10 improvement in kinetics of sodium alanate and identified potential pathway to increased storage capacity

Anticipated FY 2004 Accomplishments

- Demonstrate 10,000 psi tanks achieving 2005 targets of 1.5 kWh/kg and 1.2 kWh/L.
- Complete construction of independent test facility for reversible solid-state storage materials.

## Fuel Cells

Goal: Develop and demonstrate fuel cell power system technologies for transportation, stationary, and portable applications.

Objectives

- Develop a 60% efficient, durable, direct hydrogen fuel cell power system for transportation at a cost of $45/kW (including hydrogen storage) by 2010 and $30/kW by 2015.
- Develop a 45% efficient reformer-based fuel cell power system for transportation operating on clean hydrocarbon or alcohol-based fuel that meets emissions standards, a startup time of 30 seconds, and a projected manufactured cost of $45/kW by 2010 and $30/kW by 2015.

- Develop a distributed generation PEM fuel cell system operating on natural gas or propane that achieves 40% electrical efficiency and 40,000 hours durability at $400-$750/kW by 2010.
- Develop a fuel cell system for consumer electronics with an energy density of 1,000 Wh/L by 2010.
- Develop a fuel cell system for auxiliary power units (3-30/kW) with a specific power of 150 W/kg and a power density of 170 W/L by 2010.

FY 2003 Status

- Current cost of vehicle fuel cell power systems: $250/kW (at 500,000 units per year)

Anticipated FY 2004 Accomplishments

- Reduce costs through demonstration of bipolar plate pilot plant production rate of 300 plates/hour.
- Reduce on-board fuel processor start-up time to <1 min. through auto-thermal technology.
- Define requirements and initiate economic analysis/study of stationary fuel cells and their associated markets.

## Technology Validation

Goal: Validate integrated hydrogen and fuel cell technologies for transportation, infrastructure, and electric generation in a systems context under real-world operating conditions.

Objectives

- By 2008, validate an electrolyzer that is powered by a wind turbine at a capital cost of $300/$kW_e$ when built in quantity.
- By 2008, validate hydrogen vehicles which have greater than a 300-mile range, 2,000-hour fuel cell durability, and $3.00/kg hydrogen production cost (untaxed), and which can be safely and conveniently refueled by trained drivers.
- By 2008, validate stationary fuel cell and hydrogen internal combustion engine (ICE) systems that coproduce hydrogen and electricity from nonrenewable and renewable resources, with a 30,000-hour durability, greater than 32% efficiency, and a price of $1,250/kW or less (for volume production).
- By 2010, validate an integrated biomass/wind or geothermal electrolyzer-to-hydrogen system to produce hydrogen for $3.30/kg at the plant gate (untaxed and unpressurized).
- By 2015, validate hydrogen PEM fuel cell vehicles achieving 300+ mile range and 5,000 hours fuel cell system durability, and which can be safely and conveniently refueled by trained drivers.

FY 2003 Status

- Cost of hydrogen production from natural gas: $5.00/kg
- Fuel cell durability in a systems context of 1,000 hours

Anticipated FY 2004 Accomplishments

- Validate $3.60/kg hydrogen from natural gas when co-production of electricity is included
- Initiate “learning” demonstrations that emphasize and integrate hydrogen infrastructure and hydrogen powered vehicles to validate technology status and focus future R&D directions.

## Codes and Standards

Goal: Facilitate the creation and adoption of model building codes and equipment standards for hydrogen systems in commercial, residential, and transportation applications. Provide technical resources to harmonize the development of international standards among the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), and the Global Regulation on Pollution and Energy (GRPE) Program.

Objectives

- Complete the drafting of hydrogen building codes for the National Fire Protection Association's (NFPA's) hearing cycle.
- By 2005, facilitate the adoption of the International Code Council (ICC) codes in three key regions: Northeast, Mid-Atlantic, and Midwest.
- By 2006, support and facilitate the completion and adoption of the ISO standards for hydrogen refueling and storage.
- By 2008, support and facilitate the completion and adoption of the revised NFPA 55 standard for hydrogen storage with data from the technology validation program element activities and the experimental project for underground bulk storage of hydrogen.
- By 2010, support and facilitate U.S. adoption of a Global Technical Regulation (GTR) for hydrogen fuel cell vehicles under the United Nations Economic Commission for Europe World Forum for Harmonization of Vehicle Regulations Working Party on Pollution and Energy under the GRPE program (ECE-WP29/GRPE).

FY 2003 Status

- Developed a plan for international safety standards (currently under review)

Anticipated FY 2004 Accomplishments

- Collaborate with ICC and NFPA to develop first-order continuing education for code officials.
- Establish a coordination plan with education sub-program activity to run workshops for state and local officials.
- Initiate negotiations with critical standards development organizations and develop draft generic licensing agreement and estimate of costs.

## Safety

Goal: Develop and implement the practices and procedures that will ensure safety in the operation, handling, and use of hydrogen and hydrogen systems for all DOE-funded projects.

Objectives

- Draft a comprehensive safety plan to be completed in collaboration with industry. The plan will initiate the research necessary to fill safety information gaps and enable the formation of a Safety Review Panel by 2004.
- Integrate safety procedures into all DOE project funding procurements. This will ensure that all projects that involve the production, handling, storage, and use of hydrogen incorporate project safety requirements into the procurements by 2005.
- Publish a handbook of Best Management Practices for Safety by 2010. The Handbook will be a "living" document that will provide guidance for ensuring safety in future hydrogen endeavors.

FY 2003 Status

- Completed draft safety guidelines to be used by all DOE Hydrogen Program projects
- Anticipated FY 2004 Accomplishments
- Assemble panel of experts in hydrogen safety to provide expert technical guidance to funded projects.
- Develop in collaboration with NASA, the U.S. Department of Transportation, and the U.S. Department of Commerce, a search protocol on component and system safety.
- Identify areas of additional study and research for failure modes scenarios.
- Establish annual review criteria for safety.

## Education

Goal: Educate key audiences about fuel cell and hydrogen systems to facilitate commercialization and market acceptance of these technologies.

Objectives

By 2010 –

- Achieve a fourfold increase in the number of students and teachers who understand the concept of a hydrogen economy and how it may affect them.
- Achieve a fourfold increase in the number of state and local government representatives who understand the concept of a hydrogen economy and how it may affect them.
- Achieve a twofold increase in the number of large-scale end-users who understand the concept of a hydrogen economy and how it may affect them.
- Launch a comprehensive and coordinated public education campaign about the hydrogen economy and fuel cell technology.

FY 2003 Status

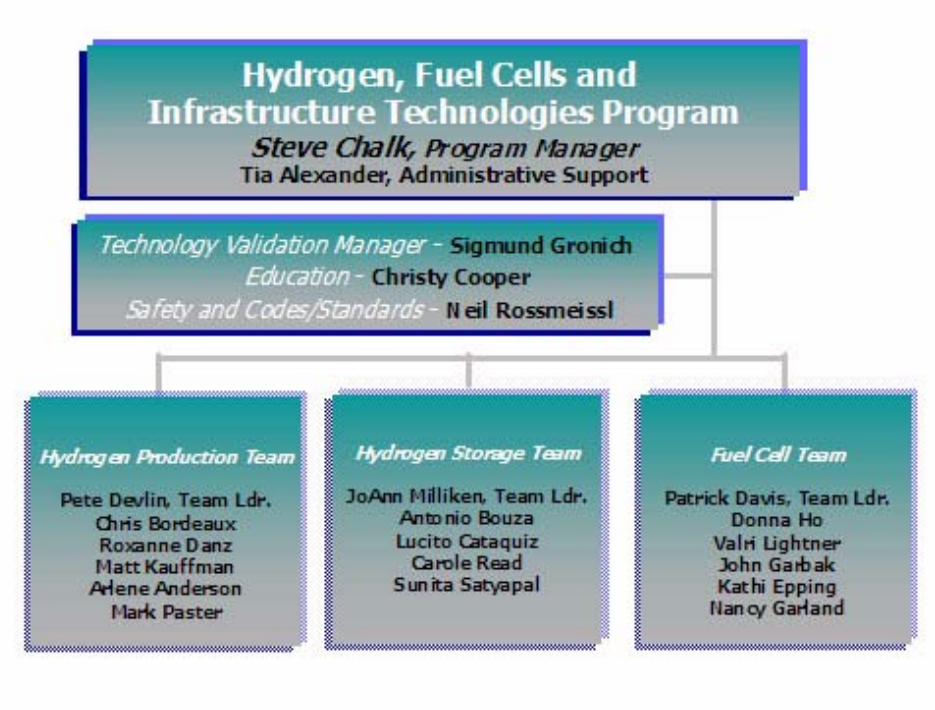
- Developed a comprehensive, long-term plan to educate multiple audiences.

Anticipated FY 2004 Accomplishments

- Launch new middle school and high school hydrogen technology curricula and teacher professional development program.
- Initiate series of hydrogen technology learning workshops for state and local governments.

## Hydrogen, Fuel Cells, and Infrastructure Technologies Program Management

This report documents the progress made by the DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program during FY 2003. The following sections of the report contain 161 individual progress reports of projects currently being conducted or newly initiated. These reports provide technical details on the progress being made to achieve the goals and technical targets of the Hydrogen, Fuel Cells and Infrastructure Technologies Program. The following organization chart shows its management structure, and the list of Technology Development Managers provides contact information and shows management responsibilities.



| Hydrogen Production Team | |
|---|---|
| **Pete Devlin**<br>(202) 586-4905<br>Peter.Devlin@ee.doe.gov | • Team Leader, Hydrogen Production<br>• Overall Hydrogen Production R&D<br>• FreedomCAR and Fuel Partnership Hydrogen Production Technical Team |
| **Roxanne Danz**<br>(202) 586-7260<br>Roxanne.Danz@ee.doe.gov | • Hydrogen Production with biomass feedstock and direct water splitting using photolytic processes<br>• NAS coordination |
| **Chris Bordeaux**<br>(202) 586-3070<br>Christopher.Bordeaux@ee.doe.gov | • Integrated Power Parks<br>• Uninterruptible Power Systems<br>• $H_2$ Infrastructure Validation<br>• California Fuel Cell Partnership<br>• International Partnership for $H_2$ Economy (IPHE) |
| **Matt Kauffman**<br>(202) 586-5824<br>Matthew.Kauffman@ee.doe.gov | • Cross-cutting Analyses<br>• Electrolysis and Electricity Infrastructure Integration |
| **Arlene Anderson**<br>(202) 586-3818<br>Arlene.Anderson@ee.doe.gov | • Distributed $H_2$ Production (Natural Gas, Petroleum Feedstocks)<br>• Coordinate with Fossil Energy on Coal-Based $H_2$ Production (Board of Directors, Pittsburgh Coal Conference)<br>• Multi-Year R,D&D Plan Development (lead)<br>• Platinum Mining & Recovery |
| **Mark Paster**<br>(202) 586-2821<br>Mark.Paster@ee.doe.gov | • FreedomCAR and Fuel Partnership Hydrogen Delivery Technical Team<br>• Overall Feedstock/Production/Delivery Strategy and Analysis<br>• High Temperature Thermochemical Water Splitting for $H_2$ Production |

| Cross-Cutting Functions | |
|---|---|
| **Sig Gronich**<br>(202) 586-1623<br>Sigmund.Gronich@ee.doe.gov | • Manager, Technology Validation<br>• Overall Technology Validations for Transportation and Stationary Applications |
| **Neil Rossmeissl**<br>(202) 586-8668<br>Neil.Rossmeissl@hq.doe.gov | • Manager, $H_2$ Safety, Codes & Standards and Utilization<br>• Hydrogen Technical Advisory Panel<br>• IEA $H_2$ Implementing Agreement Executive Committee |
| **Christy Cooper**<br>(202) 586-1885<br>christy.cooper@ee.doe.gov | • Manager, Hydrogen Education<br>• California Fuel Cell Partnership Communications Team<br>• NextEnergy Educational Working Group |

| Hydrogen Storage Team | |
|---|---|
| **JoAnn Milliken**<br>(202) 586-2480<br>JoAnn.Milliken@ee.doe.gov | • Team Leader, Hydrogen Storage<br>• Hydrogen Storage Budget<br>• FreedomCAR and Fuel Partnership Hydrogen Storage Technical Team<br>• International Hydrogen Storage Activities<br>• BES Liaison |
| **Lucito Cataquiz**<br>(202) 586-0729<br>Lucito.Cataquiz@ee.doe.gov | • Support Service COTR<br>• Costing/Financial Status Reports |
| **Carole Read**<br>(202) 586-3152<br>Carole.Read@ee.doe.gov | • Metal Hydride Storage Materials<br>• New Materials for Hydrogen Storage<br>• Alanate Working Group<br>• Education Liaison |
| **Sunita Satyapal**<br>(202) 586-2336<br>sunita.satyapal@ee.doe.gov | • Carbon-Based Storage Materials<br>• Carbon Working Group<br>• Chemical Hydrogen Storage Materials<br>• Safety Liaison<br>• Fuel Cell Seminar Organizing Committee |
| **Antonio Bouza**<br>(202) 586-4563<br>antonio.bouza@ee.doe.gov | • Compressed and Liquid Hydrogen Storage<br>• Testing and Analysis<br>• Delivery Liaison<br>• Technology Validation Liaison<br>• International Hydrogen Infrastructure Group (IHIG) |

| Fuel Cell Team | |
|---|---|
| **Pat Davis**<br>(202) 586-8061<br>Patrick.Davis@ee.doe.gov | • Team Leader, Fuel Cell<br>• Overall Fuel Cell Systems<br>• FreedomCAR and Fuel Partnership Fuel Cell Technical Team |
| **Kathi Epping**<br>(202) 586-7425<br>Kathi.Epping@ee.doe.gov | • Stationary Fuel Cells System Development & Demonstration<br>• Back-up power/peak shaving fuel cell systems<br>• Fuel Cell Economic Analysis |
| **John Garbak**<br>(202) 586-1723<br>John.Garbak@ee.doe.gov | • Fuel Cell Vehicle Demonstration<br>• Liaison with 21st Century Truck<br>• Fuel Cells for APUs, portable power, and off-road application<br>• Compressors/Expanders |
| **Nancy Garland**<br>(202) 586-5673<br>Nancy.Garland@ee.doe.gov | • National Lab Fuel Cell R&D<br>• Sensors<br>• Cost Analyses |
| **Donna Ho**<br>(202) 586-8000<br>Donna.Ho@ee.doe.gov | • Transportation Fuel Cells<br>• Bipolar Plates<br>• SBIR Program |
| **Valri Lightner**<br>(202) 586-0937<br>Valri.Lightner@ee.doe.gov | • Fuel Processing<br>• MEA R&D<br>• Budget Coordination<br>• Intra-agency Coordination |

## Updated Website

The website for the Hydrogen, Fuel Cells, and Infrastructure Technologies Program has been updated and expanded to include not only Program information, but information about hydrogen and hydrogen fuel cell vehicles in general.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The photograph on the next page was taken at the October 8, 2003 DOE program management meeting and includes managers from the Offices of Nuclear Energy (NE), Fossil Energy (FE), Science (SC), and Energy Efficiency and Renewable Energy (EERE), and personnel providing critical support to the program. The Hydrogen Program Merit Review and Peer Evaluation Meeting will be held May 24-27, 2004, in Philadelphia. We hope that you will join us there.

Steven G. Chalk, Hydrogen Program Manager
Office of Hydrogen, Fuel Cells, and Infrastructure Technologies
Energy Efficiency and Renewable Energy


**The Hydrogen Program Team:** 1. John Petrovic (LANL); 2. Neil Rossmeissl (EERE); 3. Mark Paster (EERE); 4. Tia Alexander (EERE); 5. John Houghton (SC); 6. Ed Schmetz (FE); 7. Valri Lightner (EERE); 8. Tony Bouza (EERE); 9. David Henderson (NE); 10. Michael Shapiro (TMS); 11. Patrick Davis (EERE); 12. Art Hartstein (FE); 13. Carole Read (EERE); 14. John Garbak (EERE); 15. Lauren Inouye (Sentech); 16. Amy Taylor (NE); 17. Steve Chalk (EERE); 18. Lucito Cataquiz (EERE); 19. Roxanne Danz (EERE); 20. Nancy Garland (EERE); 21. Pete Devlin (EERE); 22. Sunita Satyapal (EERE); 23. Christy Cooper (EERE); 24. Donna Ho (EERE); 25. Rich Bechtold (QSS); 26. Bill Cleary (ANL); 27. Larry Blair (Consultant); 28. Chris Bordeaux (EERE); 29. Matt Kauffman (EERE); 30. Barbara Wolfe (QSS); 31. Reeshemiah Schuler (CSMI); 32. Arlene Anderson (EERE); 33. Lowell Miller (FE); 34. Harriet Kung (SC); 35. Melissa Lott (QSS); 36. Marsha Quinn (EERE); 37. Kristen Rannels (Sentech); 38. Sigmund Gronich (EERE); 39. JoAnn Milliken (EERE); 40. Bobi Garrett (NREL); 41. Kathi Epping (EERE); 42. Tom Morehouse (ETM Strategic Consulting); 43. Peter Alyanakian (DOE Philadelphia Regional Office)